Transition from Electrostatic to Electromagnetic Mode in Atmospheric Pressure RF Ar Inductively Coupled Plasma

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The transitions between electrostatic (E) and electromagnetic (H) discharge modes of typical Inductively Coupled Plasma (ICP) were investigated in many literatures, but mainly for low pressure discharges [1-2]. In this paper, the dynamics of E-H discharge mode transition of Ar ICP in atmospheric pressure with a driving frequency (radio frequency, rf) range of 0.5~1.5 MHz and a moderate rf power of about 2~5 kW are investigated experimentally. The transition parameters are calculated by using a proposed model, and the calculated results are compared with that of the experimental results.

The plasmas were generated by applying an SIT (Static Induction Transistor) inverter power source, the maximum output power of which was about 20kW with a frequency range of 0.2~2.0 MHz. A matching network was employed to optimize the loading impedance and the power coupling. High speed imaging, using the 'FastCam-Ultima-SE' camera with a frame speed of 4500 f/s, was performed to observe the transition dynamics.

The dynamics of E-H discharge mode transition can briefly be described as follows: At the starting of ignition, multiple streamer-like discharges (E-discharge) develop due to the strong electrostatic field, E_z (~100kV/m) generated by the rf coil voltage. These streamer-like discharges develop immediately after starting the ignition since the electron heating time for ionization is found to be much faster (~10^{-8} sec) than the rf period (~10^{-6}). The discharge paths then connect among the streamers and transform the streamers into the ring-shaped discharges (H-discharge) due to the induced electric field, E_θ (~2.5kV/m). For the time being, the H-discharge develops downward thereby forming the steady state plasmas due to plasma heating. With the proposed model, the gross time for transition from E- to H-mode, that is, the connection time of neighboring vertical discharge paths is found to be about 4 ms, which agrees well with the experimental result (2~3 ms).

The plasma loading impedance and absorbed power of E-and H-discharge are measured. During the E-mode, the absorbed power is very low (maximum about 0.2 kW) while becomes high and remains almost constant (2~5 kW) after the transition, which confirms the high power coupling in the H-mode as seen in [1]. In conclusion, the experimental results suggest us that the formation of multiple streamer-like discharge paths followed by the ring-shaped azimuthal discharges leads to ignite the high pressure rf inductively coupled plasmas.

References

[1] K. Ostrikov et. al., IEEE Trans. of Plas. Sci., **30**, 128 (2002).
[2] G. Cunge et. al., Plasma Sourc. Sci. Technol., **8**, 576 (1999).

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